International Journal of Engineering

Journal Homepage: www.ije.ir

Experimental Study on Bonding CFRP to Fiber Concrete Beam Considering the Effect of using Nanographene Oxide in Improving the Mechanical Properties of Polyamine Resin

M. R. Halvaeyfar[a], S. M. Mirhosseini[a]*, E. Zeighami[a], A. Hassani Joshaghani[b]

[a] *Department of Civil Engineering, Arak Branch, Islamic Azad University, Arak, Iran*
[b] *Department of Chemical Engineering, Arak Branch, Islamic Azad University, Arak, Iran*

PAPER INFO

Paper history:
Received 09 February 2022
Received in revised form 21 March 2022
Accepted 31 March 2022

Keywords:
Graphene Oxide
Carbon Fiber
Fiber Concrete Beams
Strengthening
Retrofitting
Epoxy Resin

ABSTRACT

This research examined the effect of nanographene oxide in enhancing the mechanical properties of polyamine resin for better adhesion of carbon-fiber-reinforced polymer (CFRP) to a fiber-reinforced concrete beam. To this purpose, 33 fiber-reinforced concrete beams retrofitted with CFRP of lengths 50 cm, 35 cm, and 20 cm and widths 3 cm, 6 cm, and 10 cm were experimentally studied. Graphene oxide weight percentages of 1, 2, and 3 percent were considered, and the corresponding cases were compared with the case of a retrofitted beam without graphene oxide. According to the results of experiments on 12 of the beams, as the nanomaterial in the adhesive increases from 1 to 2 and 3%, the values of maximum load-carrying capacity, maximum mid-span deflection, beam stiffness, and beam toughness exhibited 46,19, 27, and 5 %, respectively, relative to the case of the beam reinforced with CFRP and without graphene oxide. Subsequently, given the close results of the beams reinforced with 2 and 3% graphene oxide. The 2% graphene oxide was used in the rest of the samples to investigate the effect changes in the number of layers, length, and width of the CFRP on the mechanical properties of the concrete beam. The results indicated that an increase in the number of layers, length, and width of CFRP results in an increase in the load-carrying capacity and deformability of the fiber-reinforced concrete beam

***doi**: 10.5829/ije.2022.35.08b.09*

1. INTRODUCTION

The increasing trend in the demand for structural reinforcement and strengthening can be due to a failure to follow regulations during construction, weakness of the structure against lateral forces, exposure to corrosion, changes in regulations, changes in usage, and old age, among other factors. In general, structural retrofitting and strengthening can be defined as an intelligent modification of structural properties of a building aimed at improving future seismic performance. Various strengthening methods have been considered suitable for reinforced concrete structures. Steel binding, increasing the cross-sectional area via concreting and adding rebars, strengthening via steel plates, epoxy injection, integration with prestressed cables, employing seismic techniques, and using fiber-reinforcement polymer (FRP) are examples of these methods. Among composites, the carbon-fiber-reinforced type is used more frequently than other types for concrete structures due to its higher strength, higher stiffness-to-weight ratio, better corrosion resistance, shorter construction time, and better durability [1-6]. Numerous studies have been conducted in recent years on the strengthening of reinforced concrete members, such as beams [7-10], slabs, columns [11], beam-to-column [12], connections, and other members [13]. Providing the debonding of carbon-fiber-reinforced polymer (CFRP) from the concrete surface is limited, this product may be considered to possess all the parameters required to strengthen reinforced concrete structures [14]. Various methods have been introduced to maximize the utility of the tensile capacity of CFRP under loading

*Corresponding Author Institutional Email: m-mirhoseini@iau-arak.ac.ir (S. M. Mirhosseini)

Please cite this article as: M. R. Halvaeyfar, S. M. Mirhosseini, E. Zeighami, A. Hassani Joshaghani, Experimental Study on Bonding CFRP to Fiber Concrete Beam Considering the Effect of using Nanographene Oxide in Improving the Mechanical Properties of Polyamine Resin, ***International Journal of Engineering, Transactions B: Applications***, Vol. 35, No. 08, (2022) 1524-1532

while preventing debonding between the CFRP and the reinforced concrete [15-17]. Most of these methods attempt to prevent debonding by using CFRP, steel plates, bolts, or a combination of these at the end of the connection between CFRP and concrete. In recent years, some research has been conducted on limiting fiber-concrete debonding by using nanomaterials to strengthen resins. Due to their large specific area, these materials have improved the mechanical properties of resins. An example of these materials is carbon nanotube (CNT) particles, which have been extensively studied by researchers [18-20]. These particles have been reported to increase the tensile strength, flexural strength, toughness, strain, and modulus of elasticity [21-24]. Another example of nanomaterials is graphene oxide, which is layered. Most studies have investigated the chemical effect of this material on the mechanical capacity of resins [25-28]. Little research has addressed the application of nanographene oxide in enhancing the properties of resins and in the strengthening of reinforced concrete structures. Acar et al. [29] carried out studies on the mechanical properties of monolayer prepreg (MP) and graphene-reinforced monolayer prepreg (GMP) composites aimed at improving resin properties to reinforce a concrete beam. The results indicated that adding graphene improved the mechanical properties of the resin and increased the tensile strength of the system. In another study, Wang et al. [30] demonstrated that participation by nanographene in epoxy resin improves the tensile strength and maximum strain of composite beams and significantly affects their abrasion properties and long-term durability. The present work experimentally researches the influence of nanographene oxide on improving the mechanical properties of polyamine resin in strengthening a fiber-reinforced concrete beam using CFRP. For this purpose, 33 fiber-reinforced concrete beams were prepared and subjected to four-point loading. Moreover, the influence of changing the number of layers and the length and width of the CFRP on the increase in the load-carrying capacity and deformability of the fiber-reinforced concrete beam was studied.

2. MATERIALS AND EXPERIMENTAL SETUP

In this research, an experimental setup was defined to determine the load-carrying capacity of the fiber-reinforced concrete beam strengthened using CFRP. The epoxy adhesive used to attach the CFRP to the tensile region of the fiber-reinforced concrete was polyamine resin with nanographene oxide. The fiber-reinforced concrete beam samples were 50 cm in length with cross-sectional dimensions of 10×10 cm and contained 1% Volumetric steel fibers. 3 samples were made for each type and their average was considered.

The specifications of the CFRP, number of CFRP layers, percentage of nanographene oxide, and number of identical test samples are displayed in Table 1. In this table, the letters Le, W, and L represent the length, width, and the number of layers of the CFRP, respectively, and the letter G denotes the weight percent of nanographene oxide used in the polyamine resin. For instance, the sample Le50-W3-L1-G2 is reinforced with one layer CFRP with a length of 50 cm, a width of 3 cm, and 2 wt% of nanographene oxide in the resin.

2. 1. Materials

Unidirectional CFRP with a weight of 180 g/m^2 was used in this research to reinforce the beams. The specifications of the CFRP used are shown in Table 2. Concrete with an average compressive strength of 32.8 Mpa and a slump of 48 mm was used to prepare the beams. The cement used was of Type-5 with silica used in 5 different particle size ranges to maintain gradation continuity. The largest grain size was 5 mm, and microsilica was used to fill the space between the

TABLE 1. Specifications of fiber concrete samples

Number of similar samples	Nano weight percentage	Specifications of CFRP			Sample	Number
		No. of layers	Length(cm)	Wide(cm)		
3	___	___	50	___	No CFRP	1
3	___	1	50	10	Le50-W10-L1-G0	2
3	1	1	50	10	Le50-W10-L1-G1	3
3	2	1	50	10	Le50-W10-L1-G2	4
3	3	1	50	10	Le50-W10-L1-G3	5
3	2	2	50	10	Le50-W10-L2-G2	6
3	2	3	50	10	Le50-W10-L3-G2	7
3	2	1	20	10	Le20-W10-L1-G2	8
3	2	1	35	10	Le35-W10-L1-G2	9
3	2	1	50	3	Le50-W3-L1-G2	10
3	2	1	50	6	Le50-W6-L1-G2	11

TABLE 2. Mechanical specifications of CFRP

Modulus of elasticity (Gpa)	Tensile strength (Mpa)	Weight (g/m^2)	Thickness (mm)	
230	3800-4000	180	0.3	quantity

grains. Furthermore, a lubricant was used to improve the performance of concrete. The details of the concrete mix design according to ASTM C33 are displayed in Table 3.

Drinking water with a water-to-cement ratio of 0.35 was used in the mix design. The fibers in the concrete were made of metal and had a length of 3 cm and a diameter of 0.8 mm with hooks at the ends (Figure 1). The yield strength of the fibers was 385 MPa.

Epoxy resin based on a polyamine chemical radical with a specific weight of 1 g/cm^3 and tensile strength of 14 Mpa was used in the present research. Nanographene oxide was utilized to modify the mechanical properties of the epoxy resin. The nanographene oxide had a particle thickness of 3.7-4 nm and a purity of 99%. The chemical radical of the nanographene oxide used was in the range of 6-10 layers. For better mixing of the nanographene oxide in the adhesive, a solvent consisting of Xylene, MEK, and N. Butanol with volume fractions of 70, 15, and 15 percent, respectively. First, the solvent was solved in Part A of the resin, and the nanographene oxide was added. Then, the mixture was shaken for 5 minutes and placed in the ultrasonic device for 30 minutes for the nanoparticles to be dispersed. Ultimately, the hardener (part B) of the resin was added to the adhesive several minutes before use. The solvent possessed 10% of the total weight of the resin.

2. 2. Test schedule In order to prepare the fiber-reinforced concrete beam samples, first, the dry aggregates were mixed in the mixer. In the meanwhile, micro silica, metal fibers, water, and lubricant were added in that order. Mixing was allowed to continue for 10 minutes. Subsequently, horizontal metal molds were filled with the mixture in three steps, and the mixture was compacted for 3 minutes on a vibration table in each step.

After 24 hours, the samples were demolded and were then kept for 28 days in a curing tank according to ASTM C156 (see Figure 2).

At the end of the 28 days, the weak concrete coating on the surface of the samples was removed, and the samples were repaired using restorative materials. After the surfaces were prepared, the CFRP was bonded to the tensile region of the beam using the liquid adhesive prepared beforehand. For full adhesion between the concrete beam and the CFRP, the air trapped under the CFRP was forced out via rolling. Then, the strengthened samples were maintained at room temperature for one week before loading (Figure 3). After the carbon-fiber-reinforced samples were prepared, they were subjected to four-point loading using a 250 kN STM 250 jack with a loading rate of 0.1 mm/min according to ASTM C78, as shown in Figure 4, and the deflection of the beam span was measured using a linear variable differential transformer (LVDT) gage.

3. EXPERIMENTAL RESULTS

In this section, the results of four-point loading on the fiber-reinforced concrete beam with a length of 50 cm and cross-sectional dimensions of 10×10 cm reinforced with CFRP are presented. The load was applied by the jack at a constant rate of 0.1 mm/min, and the displacement midspan of the beam was measured by the strain gauge. The maximum load, midspan deflection at

TABLE 3. Weight values of materials used in fiber concrete mixing design

Aggregate (mm)					Superplasticizer	Micro silica	Fiber	Water	Cement	Materials
0-0.3	0.3-1	1-2	2-3	3-5						
180.8	259.2	235	192.9	337.5	4.6	191	80	267	763	Quantity(kg/m^3)

Figure 1. Synthetic metal fibers

Figure 2. Curing stage of fiber concrete beams

Figure 3. Step of removing trapped air under the CFRP using the roller method

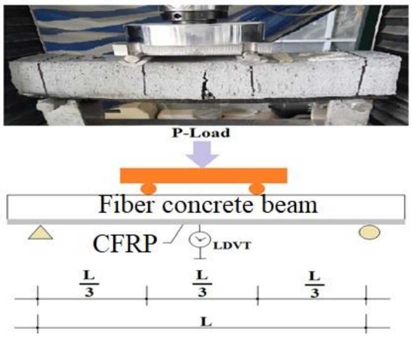

Figure 4. Preparation of reinforced fiber concrete beams for 4-point loading operations

the maximum load, initial stiffness (slope of the initial part of the force-deflection graph), and the toughness (area under the force-deflection graph), which were obtained automatically from the loading machine, are displayed in Table 4. This table draws a comparison between the strengthened fiber-reinforced concrete beam with various numbers of layers, lengths, and widths of CFRP and different weight percentages of nanographene oxide in the epoxy adhesive. Several instances of the tests performed on the fiber-reinforced beam strengthened at the tensile region using CFRP are displayed in Figure 5.

3. 1. Effect of Weight Percent of Nanographene Oxide This section addresses the effect of the weight percentage of nanographene oxide in the epoxy adhesive for improving the adhesive properties given the experimental results for the maximum load-carrying capacity, maximum deflection, initial stiffness, and toughness. The results pertaining to the maximum load-carrying capacity, maximum deflection, initial stiffness, and toughness with respect to changes in nanographene oxide are shown in Table 5.

TABLE 4. The results read from the 4-point jack machine on the reinforced fiber concrete beam

Toughness (N.m)	Initial Stiffness (kN/m)	Maximum Deflection Δ (mm)	Ultimate load Pu (KN)	Sample	Number
28.6	7361	1.44	10.6	No CFRP	1
36.3	8312	1.59	13.3	Le50-W10-L1-G0	2
36.6	9212	1.65	15.2	Le50-W10-L1-G1	3
36.7	9255	1.88	17.4	Le50-W10-L1-G2	4
38.1	10543	1.89	19.4	Le50-W10-L1-G3	5
44.4	11627	2.58	30	Le50-W10-L2-G2	6
60.1	14485	2.72	39.4	Le50-W10-L3-G2	7
36.4	8717	1.60	13.5	Le20-W10-L1-G2	8
36.5	9880	1.67	16.5	Le35-W10-L1-G2	9
36.0	9127	1.64	14.9	Le50-W3-L1-G2	10
36.3	9223	1.7	16.7	Le50-W6-L1-G2	11

Figure 5. A few examples of fiber reinforced concrete beams reinforced with CFRP

As seen in the table, a comparison of Le50W10L1G0, Le50W10L1G1, Le50W10L1G2, and Le50W10L1G3 with equal lengths, widths, and numbers of layers of CFRP and a change in the weight of graphene oxide from 0 to 1, 2, and 3 percent shows an increase in the ratio of the maximum load exerted on the beam from 1.14 to 1.31 and 1.46, respectively.

Similarly, the midspan deflection ratio increased from 1.037 to 1.18 and 1.19, respectively, the initial stiffness ratio increased from 1.11 to 1.12 and 1.27, respectively, and the toughness ratio increased from 1.003 to 1.01 and 1.05, respectively. These results indicate that a rise in the

TABLE 5. Influence of graphene oxide content on polyamine resin in mechanical properties of fiber concrete beams

$\frac{T}{T}$ *No Graphen*	$\frac{K_{int}}{K_{int}}$ *No Graphen*	$\frac{\Delta_{max}}{\Delta_{max}}$ *No Graphen*	$\frac{P_U}{P_U}$ *No Graphen*	$\frac{\Delta_{max}}{\Delta_{max}}$ *No CFRP*	$\frac{P_U}{P_U}$ NO CFRP	Toughness (N.m)	Initial Stiffness (Kn/m)	Maximum Deflection Δ (mm)	Ultimate load Pu (Kn)	Sample
0.78	0.88	0.91	0.79	1	1	28.6	7361	1.44	10.6	No CFRP
1	1	1	1	1.1	1.25	36.3	8312	1.59	13.3	Le50-W10-L1-G0
1.003	1.11	1.037	1.14	1.14	1.44	36.6	9212	1.65	15.2	Le50-W10-L1-G1
1.01	1.12	1.18	1.31	1.30	1.64	36.7	9255	1.88	17.4	Le50-W10-L1-G2
1.05	1.27	1.19	1.46	1.31	1.83	38.1	10543	1.89	19.4	Le50-W10-L1-G3

weight of graphene oxide has improved the adhesion between the epoxy adhesive and concrete. However, the above data show that the results corresponding to the use of 2 and 3% nanographene oxide were very close. Hence, the 2 wt% was used for the rest of the work in the research. It was also observed that the maximum load endured by the fiber-reinforced beam strengthened with CFRP and graphene oxide weight percentages of 0, 1, 2, and 3% were higher than those of the non-strengthened fiber-reinforced concrete beam by 25, 44, 64, and 83%, respectively. These increases were respectively 10, 14, 30, and 31% for the midspan deflection. The results corresponding to the effect of the weight percentage of graphene oxide are shown in Figure 6.

3. 2. Effect of Number of Layers of CFRP on the Results

This section addresses the influence of the number of layers of the CFRP with a length of 50 cm and a width of 10 cm considering 2 wt% of nanographene oxide in the epoxy adhesive. As seen in Table 6, a comparison of Le50W10L1G2, Le50W10L2G2, and Le50W10L3G2 with constant lengths and widths of CFRP, 2 wt% of graphene oxide, and a change in the number of layers of CFRP from 1 to 2 and 3 shows an increase in the maximum load exerted on the beam from17.4 to 30 and 39.4 kN, respectively. Similarly, the midspan deflection increased from 1.88 to 2.58 and 2.72 mm, respectively, the initial stiffness increased from 9255 to 11627 and 14485 kN/m, respectively, and the toughness increased from 36.7 to 44.4 and 60.1 Nm, respectively. These results indicate that an increase in the number of layers of CFRP improves the load-carrying capacity and flexibility of the fiber-reinforced concrete beam. Moreover, Figure 7 indicates a downward jump in force at the maximum load point. This jump becomes more severe as the number of layers increases. This occurs due to a tear in the CFRP and its inability to withstand force any longer. The fracture of the concrete beam occurs immediately after the fracture of the CFRP.

3. 3. Effect of a Change in the Length of CFRP on the Results

This section investigated the influence of a change in the length of the CFRP from 50 to 35 and 20 cm with a width of 10 cm, a single layer of CFRP, and 2

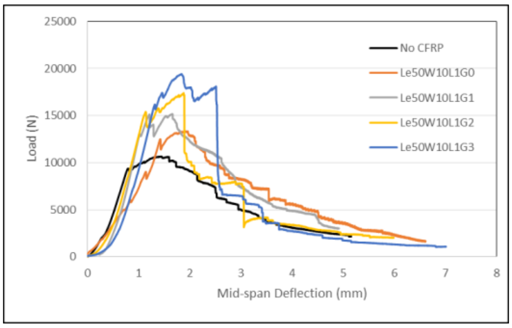

Figure 6. Effect of weight percentage of graphene oxide material used in the epoxy adhesive on the load-displacement diagram of fiber reinforced concrete beams reinforced with CFRP

TABLE 6. Influence of the number of layers of CFRP on the mechanical properties of fiber concrete beams

$\frac{T}{T}$ *No Graphen*	$\frac{K_{int}}{K_{int}}$ *No Graphen*	$\frac{\Delta_{max}}{\Delta_{max}}$ *No Graphen*	$\frac{P_U}{P_U}$ *No Graphen*	$\frac{\Delta_{max}}{\Delta_{max}}$ *No CFRP*	$\frac{P_U}{P_U}$ NO CFRP	Toughnes s(N.m)	Initial Stiffness (kN/m)	Maximum Deflection Δ (mm)	Ultima te load Pu (kN)	Sample
1.01	1.12	1.18	1.31	1.30	1.64	36.7	9255	1.88	17.4	Le50-W10-L1-G2
1.22	1.4	1.62	2.25	1.79	2.83	44.4	11627	2.58	30	Le50-W10-L2-G2
1.65	1.74	1.71	2.96	1.89	3.72	60.1	14485	2.72	39.4	Le50-W10-L3-G2

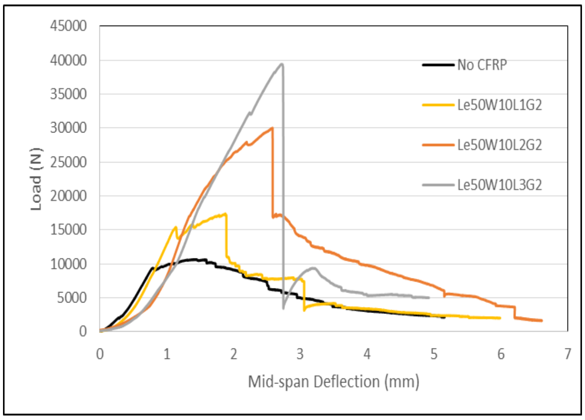

Figure 7. Effect of the number of layers of CFRP used to reinforce the fiber beam in the load-displacement diagram of the beam by considering two weight percent of the amount of graphene nano oxide in epoxy adhesive

wt% of nanographene oxide in the adhesive. As summarized in Table 7, a comparison of Le50W10L1G2, Le35W10L1G2, no CFRP, and Le20W10L1G2 with equal widths, one layer of CFRP, 2 wt% of graphene oxide, and with a change in the length of CFRP from 50 to 35 and 20 cm showed increases of 64, 55 and 27% in the maximum applied load compared to the beam sample without CFRP. Similarly, the midspan deflection increased from 30 to 16 and 11%, respectively. In addition, the results indicated that the toughness of the beam increases from 27.2 to 27.6 and 28.3% with an increase in the CFRP length from 20 to 35 and 50 cm. These results, displayed in Figure 8, demonstrate an improvement in the load-carrying capacity and flexibility of the strengthened fiber-reinforced beam given the use of the whole surface area of the tensile region of the concrete for strengthening. Furthermore, Figure 8 shows that the overall shapes of the load-deflection graphs of the three samples are almost identical. Initially, the load-carrying increases with a gentle slope, followed by a downward jump due to the formation of microcracks.

Subsequently, as the fibers come into play, the load-carrying capacity begins to rise again, followed by a strong decrease as the CFRP fractures.

3. 4. Effect of a Change in the Width of CFRP on the Results

This section investigated the impact of a change in the width of the CFRP from 10 to 6 and 3 cm with a constant length of 50 cm, a single layer of CFRP, and 2 wt% of nanographene oxide in the resin. As stated in Table 8, a comparison of Le50W10L1G2, Le35W6L1G2, no CFRP, and Le20W3L1G2 with equal lengths, one layer of CFRP, 2 wt% of graphene oxide, and with a change in the width of CFRP from 10 to 6 and 3 cm showed increases of 64, 57, and 40% in the maximum load applied to the beam compared to the beam sample without CFRP. Similarly, the midspan deflection increased from 30 to 18 and 14%, respectively. In addition, the results indicated that the toughness of the beam decreases from 28.3 to 26.9 and 25.8% with an increase in the CFRP width from 10 to 6 and 3 cm. These results are also displayed in Figure 9.

TABLE 7. Influence length of CFRP on the mechanical properties of fiber concrete beams

$\frac{T}{T}$ No CFRP	$\frac{\Delta_{max}}{\Delta_{max}}$ No CFRP	$\frac{P_U}{P_U}$ No CFRP	Toughness(N.m)	Maximum Deflection Δ (mm)	Ultimate load Pu(kN)	Sample
1	1	1	28.6	1.44	10.6	No CFRP
1.28	1.30	1.64	36.7	1.88	17.4	Le50-W10-L1-G2
1.27	1.16	1.55	36.5	1.67	16.5	Le35-W10-L1-G2
1.27	1.11	1.27	36.4	1.60	13.5	Le20-W10-L1-G2

TABLE 8. Influence width of CFRP on the mechanical properties of fiber concrete beams

$\frac{T}{T}$ No CFRP	$\frac{\Delta_{max}}{\Delta_{max}}$ No CFRP	$\frac{P_U}{P_U}$ NO CFRP	Toughness (N.m)	Maximum Deflection Δ (mm)	Ultimate load Pu (kN)	Sample
1	1	1	28.6	1.44	10.6	No CFRP
1.28	1.30	1.64	36.7	1.88	17.4	Le50-W10-L1-G2
1.26	1.18	1.57	36.3	1.70	16.7	Le50-W6-L1-G2
1.25	1.14	1.4	36.0	1.64	14.9	Le50-W3-L1-G2

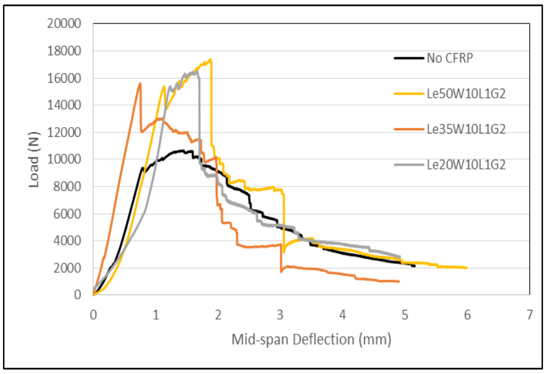

Figure 8. Effect of changing the length of carbon fiber used to strengthen the fiber beam in the load-displacement diagram of the beam by considering a layer of carbon fiber and 2% by weight of graphene nano oxide in epoxy resin

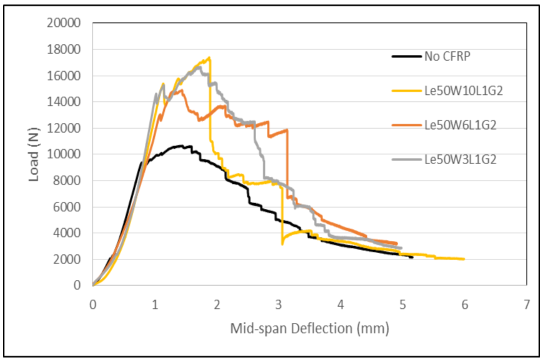

Figure 9. Effect of changing the width of carbon fiber used to strengthen the fiber beam in the load-displacement diagram of the beam by considering a layer of carbon fiber and 2% by weight of graphene nano oxide in epoxy resin

4. CONCLUSION

This research demonstrated that an increase in nanographene oxide in epoxy adhesive and the number of layers, length, and width of CFRP improve the load-carrying capacity and deformability of fiber-reinforced concrete beams. The following conclusions are drawn:

- As the weight percentage of nanographene oxide increased from 1 to 2 and 3% in the epoxy adhesive, the ultimate load-carrying capacity of a fiber-reinforced beam strengthened with a layer of CFRP with a length of 50 cm and width of 10 cm increased by 14, 31, and 46%, respectively, compared to a similar reinforced beam without nanographene oxide (Le50W10L1G0) and with an ultimate load-carrying capacity of 13.3 kN. Moreover, the results indicated a 3.7, 18, and 19% increase in the maximum midspan deflection for the strengthened beam, respectively, compared to the 1.59 maximum midspan deflection of the fiber-reinforced beam sample (Le50W10L1G0). In addition, as the weight of the nanographene oxide increased from 1 to 2 and 3% in epoxy adhesive, increases of 1.11, 1.12, and 1.27, respectively, in initial stiffness and 1.003, 1.01, and 1.04, respectively, in toughness were observed compared to the beam sample Le50W10L1G0.
- With a constant nanographene oxide weight of 2% in polyamine resin, an increase in the number of layers of CFRP from 1 to 2 and 3 was seen to increase the ultimate load-carrying capacity of the beam to respectively 1.64 to 2.83 and 3.72 times that of the non-strengthened case. Similarly, increases of 30, 79, and 89%, respectively, in the midspan deflection of the beam were observed. An increase in the number of layers of CFRP increased the initial stiffness from 9255 to 11627 and 14485 kN/m, respectively, and the toughness from 36.7 to 44.4 and 60.1 N.m.
- As the length of the CFRP increased from 20 to 35 and 50 cm, the maximum load-carrying capacity increased by 27, 55, and 64%, respectively. In addition, increases of 11, 16, and 30% were obtained from the maximum midspan deflection and 27.2, 27.6 and 28.3% for the toughness of the materials. In this case, 2% nanographene oxide was used in the polyamine resin.
- With an increase in the width of the CFRP from 3 to 6 and 10 cm, the ultimate load-carrying capacity was observed to increase by 40, 57 and 64%, respectively. The corresponding increases in the maximum midspan deflection were 14, 18, and 30%, respectively, and those in the toughness were 25.8, 26.9, and 28.3%, respectively.
- Using the results obtained in this study, due to the high resistance created in the resin, the full capacity of CFRP can be used, which is the result of significant progress in civil engineering.

5. REFERENCES

1. M. Shadmand, A. Hedayatnasab, and O. Kohnehpooshi, “Strengthening of RC beams using steel plate-fiber concrete composite jackets: Finite element simulation and experimental investigation,” ***International Journal of Engineering, Transactions A: Basics***, Vol. 35, No. 1, (2022), 73-92, doi: 10.5829/ije.2022.35.01a.07.
2. S. B. Rahimi, A. Jalali, S. M. Mirhosseini, and E. Zeighami, “Comparative experimental study of different types of fiber-reinforced polymer wrapping in repairing of reinforced concrete deep beams with circular openings,” ***International Journal of Engineering, Transactions B: Applications***, Vol. 34, No. 8, (2021), 1961-1973, doi: 10.5829/ije.2021.34.08b.17.
3. S. A. Abbas, I. F. Ali, and A. A. Abdulridha, “Behavior and strength of steel fiber reinforced self-compacting concrete columns wrapped by carbon fiber reinforced polymers strips,” ***International Journal of Engineering, Transactions B: Applications***, Vol. 34, No. 2, (2021), 382-392, doi:

10.5829/IJE.2021.34.02B.10.

4. S. Yousefi Khatuni and H. Showkati, "Buckling behavior of semi-scale steel tank with carbon fiber reinforced polymer ring subjected to lateral uniform pressure loading," ***International Journal of Engineering, Transactions A: Basics***, Vol. 32, No. 10, (2019), 1407-1415, doi: 10.5829/ije.2019.32.10a.10.

5. M. B. S. Alferjani, A. A. A. Samad, B. S. Elrawaff, and N. Mohamad, "Experimental and Theoretical Investigation on Shear Strengthening of RC Precraced Continuous T-beams Using CFRP Strips," ***International Journal of Engineering,, Transactions B: Applications,*** Vol. 28, No. 5, (2015), 671-676. doi: 10.5829/idosi.ije.2015.28.05b.04

6. A. A. Maghsudi and D. Y. Askari, "Ultimate unbonded tendon stress in CFRP strengthened post-tensioned indeterminate I-beams cast with HSCs," ***International Journal of Engineering, Transactions A: Basics***, Vol. 28, No. 3, (2015), 350-359, doi: 10.5829/idosi.ije.2015.28.03c.03.

7. M. Shadmand, A. Hedayatnasab, and O. Kohnehpooshi, "Retrofitting of Reinforced Concrete Beams with Steel Fiber Reinforced Composite Jackets," ***International Journal of Engineering, Transactions B: Applications,*** Vol. 33, No. 5, (2020), 770-783, doi: 10.5829/ije.2020.33.05b.08

8. H. Dehghani and M. J. Fadaee, "Reliabilty-based Torsional Design of Reinforced Concrete Beams Strengthened with," ***International Journal of Engineering, Transactions A: Basics,*** Vol. 26, No. 10, (2013), 1103-1110, doi: 10.5829/idosi.ije.2013.26.10a.01.

9. S. H. Hashemi, "Flexural Testing of High Strength Reinforced Concrete Beams Strengthened," ***International Journal of Engineering, Transactions B: Applications,*** Vol. 22, No. 2, (2009), 131-146.

10. M. Riyazi, M. R. Esfahani, and H. Mohammadi, "Behavior of Coupling Beams Strengthened With Carbon Fiber Reinforced Polymer Sheets," ***International Journal of Engineering, Transactions B: Applications,*** Vol. 20, No. 1, (2007), 49-58.

11. A. Agbossou, L. Michel, M. Lagache, and P. Hamelin, "Strengthening slabs using externally-bonded strip composites: Analysis of concrete covers on the strengthening," ***Composites Part B: Engineering***, Vol. 39, No. 7-8, (2008), 1125-1135, doi: 10.1016/j.compositesb.2008.04.002.

12. M. H. Mahmoud, H. M. Afefy, N. M. Kassem, and T. M. Fawzy, "Strengthening of defected beam-column joints using CFRP," ***Journal of Advanced Research***, Vol. 5, No. 1, (2014), 67-77, doi: 10.1016/j.jare.2012.11.007.

13. R. V. S. Ramakrishna Ravindra, V., "Experimental Investigation on Rehabilitation of Reinforced Cement Concrete Interior Beam-Column Joints Using CFRP and GFRP Sheets," ***International Journal of Engineering Science and Technology***, Vol. 4, No. 3, (2012), 874-881.

14. M. Hussain, A. Sharif, I. A. B. M. H. Baluch, and G. J. Al-Sulaimani, "Flexural behavior of precracked reinforced concrete beams strengthened externally by steel plates," ***Structural Journal***, Vol. 92, No. 1, (1995), 14-23.

15. M. Z. Jumaat and M. A. Alam, "Behaviour of U and L shaped end anchored steel plate strengthened reinforced concrete beams," ***European Journal of Scientific Research***, Vol. 22, No. 2, (2008), 184-196.

16. M. Amir, C. Omar, B. Brahim, and N. Kenneth, "Performance of End-Anchorage Systems for RC Beams Strengthened in Shear with Epoxy-Bonded FRP," ***Journal of Composites for Construction***, Vol. 16, No. 3, (2012), 322-331, doi: 10.1061/(ASCE)CC.1943-5614.0000263.

17. J.-W. Shi, W.-H. Cao, and B.-L. Xu, "Effect of liquid rubber modification on the bond behavior of externally bonded FRP laminate-concrete interface under dynamic loading," ***Journal of Building Engineering***, Vol. 32, No. 2, (2020), doi: 10.1016/j.jobe.2020.101533.

18. M. R. Irshidat and M. H. Al-Saleh, "Effect of using carbon nanotube modified epoxy on bond-slip behavior between concrete and FRP sheets," ***Construction and Building Materials***, Vol. 105, No. 2, (2016), 511-518, doi: https://doi.org/10.1016/j.conbuildmat.2015.12.183.

19. X. Yao, X. Gao, J. Jiang, C. Xu, C. Deng, and J. Wang, "Comparison of carbon nanotubes and graphene oxide coated carbon fiber for improving the interfacial properties of carbon fiber/epoxy composites," ***Composites Part B: Engineering***, Vol. 132, No. 3, (2018), 170-177, doi: https://doi.org/10.1016/j.compositesb.2017.09.012.

20. M. R. Irshidat, N. Al-Nuaimi, and M. Rabie, "Influence of carbon nanotubes on phase composition, thermal and post-heating behavior of cementitious composites," ***Molecules***, Vol. 26, No. 4, (2021).

21. E. Soliman, U. F. Kandil, and M. R. Taha, "Limiting shear creep of epoxy adhesive at the FRP-concrete interface using multi-walled carbon nanotubes," ***International Journal of Adhesion and Adhesives***, Vol. 33, No. 4, (2012), 36-44.

22. S. R. Abdullah, F. N. Rosli, N. Ali, N. A. Abd Hamid, and N. Salleh, "Modified Epoxy for Fibre Reinforced Polymer Strengthening of Concrete Structures," ***International Journal of Integrated Engineering***, Vol. 12, No. 9, (2020), 103-113.

23. M. R. Irshidat and M. H. Al-Saleh, "Flexural strength recovery of heat-damaged RC beams using carbon nanotubes modified CFRP," ***Construction and Building Materials***, Vol. 145, No. 6, (2017), 474-482.

24. M. R. Irshidat, M. H. Al-Saleh, and H. Almashagbeh, "Effect of carbon nanotubes on strengthening of RC beams retrofitted with carbon fiber/epoxy composites," ***Materials & Design***, Vol. 89, No. 1, (2016), 225-234.

25. H. Xu *et al.*, "Evolution of properties and enhancement mechanism of large-scale three-dimensional graphene oxide-carbon nanotube aerogel/polystyrene nanocomposites," ***Polymer Testing***, Vol. 97, No. 2, (2021), doi: https://doi.org/10.1016/j.polymertesting.2021.107158.

26. A. Sheikhmohammadi *et al.*, "Application of graphene oxide modified with 8-hydroxyquinoline for the adsorption of Cr (VI) from wastewater: Optimization, kinetic, thermodynamic and equilibrium studies," ***Journal of Molecular Liquids***, Vol. 233, No. 3, (2017), 75-88, doi: https://doi.org/10.1016/j.molliq.2017.02.101.

27. L. Wei, X. Liu, Y. Gao, X. Lv, N. Hu, and M. Chen, "Synergistic strengthening effect of titanium matrix composites reinforced by graphene oxide and carbon nanotubes," ***Materials & Design***, Vol. 197, No. 4, (2021), doi: https://doi.org/10.1016/j.matdes.2020.109261.

28. H. Ashassi-Sorkhabi, B. Rezaei-Moghadam, E. Asghari, R. Bagheri, and R. Kabiri, "Sonoelectrosynthesized polypyrrole-graphene oxide nanocomposite modified by carbon nanotube and Cu_2O nanoparticles on copper electrode for electrocatalytic oxidation of methanol," ***Journal of the Taiwan Institute of Chemical Engineers***, Vol. 69, No. 5, (2016), 118-130, doi: https://doi.org/10.1016/j.jtice.2016.08.026.

29. V. Acar, F. Cakir, H. Uysal, M. O. Seydibeyoglu, H. Akbulut, and K. M. Mosalam, "Strengthening of concrete beams by monolayer prepreg composites with and without graphene reinforcement," ***Construction and Building Materials***, Vol. 151, No. 2, (2017), 866-880, doi: https://doi.org/10.1016/j.conbuildmat.2017.06.150.

30. X. Wang, F. Tang, X. Qi, and Z. Lin, "Mechanical, electrochemical, and durability behavior of graphene nano-platelet loaded epoxy-resin composite coatings," ***Composites Part B: Engineering***, Vol. 176, (2019), doi: 10.1016/j.compositesb.2019.107103.

Persian Abstract

چکیده

در این پژوهش، تاثیر ماده‌ی نانو اکسیدگرافن در بهبود خواص مکانیکی رزین پلی‌آمین جهت بهبود در چسبندگی پارچه کربنی به تیر بتن‌الیافی مورد بررسی قرار گرفت. برای این منظور در یک کار آزمایشگاهی تعداد ۳۳ تیر بتن الیافی با استفاده از پارچه‌ی کربنی به طول مختلف ۵۰، ۳۵و۲۰ سانتی‌متر و عرض مختلف ۳، ٦ و ۱۰ سانتی‌متر مقاوم‌سازی شده‌اند، مورد بررسی قرار گرفت. مقادیر وزنی اکسید گرافن در رزین به ترتیب ۱،۲و۳ درصد بوده که با حالت تیر مقاوم‌سازی شده بدون اکسیدگرافن مقایسه شد. نتایج کار ابتدا بر روی ۱۲ تیر نشان داد که با افزایش مقدار ماده‌ی نانو در چسب از ۱به۲و۳درصد، مقادیرحداکثر ظرفیت باربری، خیز حداکثر وسط دهانه، سختی تیرو طاقت آن به ترتیب ٤٦،۱۹،۲۷و۵ درصد افزایش نسبت به حالت تیر مقاوم‌سازی شده باپارچه کربنی وبدون اکسید گرافن داشت. در ادامه با توجه به نزدیک بودن نتایج تیرهای مقاوم‌سازی شده با ۲ و۳ درصد ماده‌ی اکسید گرافن، از دودرصد اکسید گرافن در بقیه نمونه‌ها استفاده شده و تاثیر تغییر در تعداد نوار، طول و عرض پارچه کربنی در مشخصات مکانیکی تیر بتنی بررسی شد. نتایج نشان داد که با افزایش تعداد نوارهای پارچه‌کربنی و همچنین طول و عرض آنها ظرفیت باربری و شکل‌پذیری تیر بتن‌الیافی افزایش می‌یابد.